Updating the Alternative Material Selection System for Cadmium (AMSS-Cd)

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Abstract

Federal specification QQ-P-416 is used to specify cadmium plating for Army applications. Cadmium, which is currently used on many military applications to provide corrosion protection, is a hazardous material. Since it has been identified as a hazardous material, cadmium has been targeted for complete removal from Army weapon systems. Unfortunately, there is no "drop-in" replacement for cadmium. Users must choose from a variety of alternatives to suit their specific needs. With the support of the Army Acquisition Pollution Prevention Support Office (AAPPSO), the U.S. Army Tank-Automotive & Armaments Command's (TACOM) Tank-Automotive Research, Development and Engineering Center (TARDEC) and Ocean City Research Corporation (OCRC) created an Alternate Material Selection System for Cadmium (AMSS-Cd) to assist in selection of alternative materials.

The original version of the AMSS-Cd was created from available physical and performance data. Some areas were found where information is unavailable. TACOM-TARDEC sponsored three projects over the past year to update the AMSS-Cd where information is needed. These efforts included: (1) evaluating cadmium replacements for electrical connectors, (2) evaluating cadmium alternatives for fastener applications, and (3) testing of possible chromate conversion coating replacements to enhance the performance of cadmium alternatives.

Information gained from these programs added more in depth information to the applications sections of the AMSS-Cd. This information both reinforced and updated previous knowledge contained in the working document.

Introduction

Executive Order 12856 mandates that the Department of Defense (DoD) reduce their hazardous waste generation 50% by 1999. Cadmium is used on Army weapon systems as a corrosion control coating for steel and aluminum. Cadmium is a carcinogenic material and has low worker exposure and environmental discharge limits due to its high toxicity. Cadmium contributes to hazardous waste generation for Army depot facilities and contractors during both plating operations, and repair/overhaul procedures.

In "Guidance for Eliminating Cadmium from U.S. Army Weapon Systems" (see ref.), AAPPSO estimated cadmium hazardous waste handling and disposal costs for the U.S. Army. There are some very significant costs and risks associated with the continued use of cadmium in U.S. Army weapon systems that will not only affect the life cycle cost of the systems, but may also affect readiness and fielding capabilities in some extreme circumstances. Two of the costs are sited below:

- OSHA has set a 5 ppm 8-hour time weighted permissible exposure limit (PEL) for cadmium. Depots are required to upgrade their facilities to comply with the new regulations. One depot has committed $22M for an entirely new, OSHA-complying metal finishing facility. A second will reportedly spend $275K to upgrade an existing facility to provide shower and clean-up areas required for employees exposed to cadmium.

- Hazardous waste disposal costs for cadmium at one Army depot were estimated to be $60,000 per year for treatment and disposal. This does not include administrative costs associated with compliance with RCRA, or any possible additional ordinances imposed by the state or local government.

The Alternate Material Selection System for Cadmium (AMSS-Cd) was developed as a tool to help guide design and material engineers along the process of identifying an appropriate non-cadmium material for U.S. Army weapon systems. Version 1 of this system focused on the use of cadmium in plating applications. The primary types of alternate materials discussed in the system provide sacrificial and barrier corrosion protection to steel and aluminum substrates in typical Army weapon system environments, just as cadmium provides. Additional coatings that provide only a barrier to keep corrosive environments from substrate materials and alternate base materials were also briefly mentioned in the system because they are appropriate alternatives for some applications.

The AMSS-Cd requires the user to understand the requirements of the application they are examining. It then gives suggested alternate materials and accompanying specifications. Industry standards or commercial specifications have been identified when possible to assist the DoD's efforts to move away from the use of military specifications and standards. The system is a guide to help the user select an alternate material. It is not intended to be Army policy, but rather it is intended to provide guidance to the decision-maker. ***The responsibility for ensuring that the appropriate coating is selected ultimately falls upon the user of the AMSS-Cd.***

The AMSS-Cd is meant to be a living document, undergoing revision, as new materials are constantly being developed and their properties are being evaluated. Periodically, the AMSS–Cd document is meant to be revised to include all additional information. (All constructive criticism or sharing of additional test data associated with the AMSS-Cd is appreciated and comments can be forwarded to either of the paper's authors.)

Alternate Material System for Cadmium (AMSS-Cd)

The AMSS-Cd was developed through a review of available technical information on cadmium alternatives, as well as discussions with several commercial industry representatives involved with cadmium use and substitution. The system is broken down into a series of tables to help the user identify materials which may be appropriate for their application. The tables include:

Table 1: Suitable Materials for Army Applications
Table 2: Material Properties Required for Army Applications
Table 3: Material Performance in Material Property Categories

Suitable Materials for Army Applications

Table 1 of the AMSS-Cd is titled "Suitable Materials for Army Applications". This table lists the various material families used as cadmium alternatives. It indicates if they are appropriate for use in different major application areas where the U.S. Army still uses cadmium plating. The major alternative material systems are identified along with the major applications identified for the Army's use of cadmium plating. Table 1 has been included in the AMSS-Cd to help the user narrow down the list of all potential alternate material systems to just the material families that apply for the specific application of interest. Table 1 of the AMSS-Cd is included as Table 1 of this document.

Material Properties Required for Army Applications

Table 2 of the AMSS-Cd is titled "Material Properties Required for Army Applications". It lists the major Army applications of cadmium plating along with the key material properties that have been identified for the different types of cadmium applications. The list is meant to address performance requirements by most, but not all individual applications of cadmium within the category. Table 2 has been included in the AMSS-Cd to help the user narrow down the list of all potential material properties to just those that generally apply for the specific application of interest. If specific details are available for the application requirements, the information should be used to expand or further narrow the list of important properties for consideration when selecting an alternate material system. AMSS-Cd Table 2 is included as Table 2 of this document.

Material Performance in Material Property Categories

Table 3 of the AMSS-Cd is titled Material Performance in "Material Property Categories". It lists 1-10 ratings (10 being good, 1 being bad) for the alternate material systems in the key material properties that have been identified for different cadmium applications. The 1-10 ratings are described in the AMSS-Cd explanation report attached to the system. ***Table 3 is the heart of the AMSS-Cd.*** The information summarized in this table is used to select an alternative material system. Tables 1 and 2 are supplemental information that can be used to narrow down the fields of materials and properties prior to examining the performance ratings in Table 3. Sample material and property ratings from Table 3 of the AMSS-Cd are included as Table 3 of this document.

The ratings given in Table 3 are based on test data or application experience from several difference reference articles and many different types of test procedures. Whenever possible, information was used from the same test procedures to develop ratings for the same property category. This was not always possible. As an example, corrosion resistance combines data from different natural exposures, ASTM B117 salt fog testing, and other accelerated corrosion tests to allow for comparisons between some of the alternatives.

If specific data was not available for different material system thickness and surface finish combinations, it was inferred from data available for other combinations from the same material type. In some cases data was not readily available for an entire material family for a specific material property. In this situation the rating was inferred from information available from similar types of material families for the property of interest. These ratings are underlined in the AMSS-Cd and the sample of Table 3 given in this report.

Table 3 provides ratings for all of the different thicknesses and surfaces finishes described in the referenced specification. When possible ASTM standards are referenced. ***Other commercial and industry specifications can be used for these material systems.*** Different thickness and surface finish requirements can also be specified when appropriate. ***The thickness and surface finishes listed correspond only to those listed in the referenced standards and are not meant to restrict the AMSS-Cd user to these requirements.*** Additional information on other specifications is given in the explanation report for the AMSS-Cd.

Selection of an Alternate Material with the AMSS-Cd

Listed below are two examples of methods for using the ratings contained in Table 3 to help select an appropriate alternative material. The AMSS-Cd user could use either method, both in combination, or develop a customized analysis system to identify appropriate alternatives. (These two methods are only examples of possible user interaction with the system. Each user of the AMSS should develop their own system to identify an appropriate alternative.)

In the weight multiplication factor (WMF) example, the user creates a customized table of materials and performance ratings for their own application. Each performance property rating is then given its own weight factor, as determined by the importance of the properties for the function of the application. The sum of the products of the performance ratings and their WMFs for each possible material are then compared for each material. Material systems with the highest totals are then examined according to specific details for each performance or other key property category (non-performance properties such as cost) to determine the most appropriate substitute. This technique has the advantage of being quicker, and easier to customize for the relative importance of performance differences of different key property categories. The disadvantage of this method is that it treats a unit difference in rated performance as an equivalent difference within each property. For example, the difference in lubricity between ratings of 9 and 10 is 0.10, but the difference in lubricity for ratings of 5 and 6 is 0.20.

The Minimum Rating Requirement (MRR) technique requires the user to give attention to each material rating value for each key property of their application. The process will be time consuming but does allow the user to develop an understanding of the general strengths and/or weaknesses for the different alternatives for each key property they evaluate. The process includes narrowing of the total list of alternates by: (1) identifying both the appropriate materials for an application (Table 1) and the key properties for that application (Table 2); (2) prioritizing the key properties by importance; and (3) assigning minimum ratings and analyzing results for each key property listed in Table 2.

Efforts Performed to Update the AMSS-Cd

The original version of the AMSS-Cd was created from available physical and performance data. Some areas were found where information is unavailable. TACOM-TARDEC has sponsored three projects over the past year to update the AMSS-Cd where information is needed. These efforts included (1) evaluating cadmium replacements for electrical connectors, (2) evaluating cadmium alternatives for fastener applications, and (3) testing of possible chromate conversion coating replacements to enhance the performance of cadmium alternatives. Information gained from these programs added more in depth information to the applications sections of the AMSS-Cd. This information also reinforced and updated previous knowledge contained in the working document.

Cadmium Replacement in Electrical Connectors

Cadmium coatings have been used on military electrical connectors because they are compatible with the aluminum and steel materials that make up the connector and mating part bodies and do not form voluminous corrosion product that can interfere with delicate electrical contact surfaces. Electrical connector replacement is difficult due to a lack of knowledge for how newer material systems will perform for various connector applications. Therefore, an ongoing evaluation of alternative electrical connector backshell coatings is being performed. The data collected in this program will be incorporated into the AMSS-Cd upon project completion.

Potential alternatives tested included IVD aluminum, zinc/nickel, tin/zinc and Electroless nickel coatings on aluminum and steel backshells. These coatings have shown promise as alternatives based on testing conducted to eliminate cadmium from other areas. (More exotic alternatives exist, including gold or silver-based coating systems, but their application in electrical systems is typically reserved for contact surfaces rather than connector bodies.) Accelerated and natural exposure tests were used to evaluate the performance of the alternatives. Key properties including corrosion resistance, electrical conductivity, and durability were evaluated during testing.

Cadmium Alternatives for Fastener Applications

Cadmium has been used in fastener applications because of its corrosion protection properties and its attractive lubricity effects. Ion Vapor Deposited (IVD) aluminum coated fasteners with a chromate conversion coating (CCC) have shown comparable properties when dry film lubricants are applied. These fasteners plated with IVD aluminum with a CCC have shown corrosion resistance in testing, but they have been susceptible to environmentally assisted cracking (EAC). The addition of the dry film lubricants alleviated this problem in many of the tested samples.

Three dry film lubricant chemistries were tested: molybdenum disulfide, Teflon/PFTE, and calcium sulfonate. They were tested for torque-tension properties, corrosion resistance (atmospheric exposure, EAC), and breaking torque. The results have been incorporated into the AMSS-Cd and will be available when Version 2 is released.

Non-Chromate Sealers as Replacements to CCC to Enhance the Performance of Cadmium Alternatives

CCC(s) per MIL-C-5541 are the most widely used products for use as sealers on cadmium, zinc, zinc alloy, and aluminum surfaces. They are used for added corrosion protection and enhancing the adhesion of paint coatings to the base metal. CCC baths contain hexavalent chrome, a known carcinogen, that requires special wastewater treatment steps that increase the total amount of hazardous waste generated by a facility.

In this program, non-chrome sealers were identified through a literature search and evaluated for initial corrosion resistance properties on pure zinc plated steel components. Further testing was then done for replacement of the CCC on zinc alloy plating. The most promising sealers were tested over the alloys for natural and accelerated exposure testing and paint adhesion (applied through typical industry procedures). These results were compared with testing run upon the same alloys with different types of CCC. The data collected in this program will be incorporated into the AMSS-Cd upon project completion.

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References

1. Ocean City Research Corporation Final Report, "Alternate Material Selection System for Cadmium (AMSS-Cd) Version 1", prepared for U.S. Army Tank-Automotive and Armaments Command, April 1997.

2. Ocean City Research Corporation Final Report, "Details of the Alternate Material Selection System for Cadmium", prepared for U.S. Army Tank-Automotive and Armaments Command, April 1997.

3. Ocean City Research Corporation Final Report, "Guidance for Eliminating Cadmium From U.S. Army Weapon Systems", prepared for Army Material Command, Army Acquisition Pollution Prevention Support Office (AMC-AAPPSO), April 1996.

4. Ocean City Research Corporation Final Report, "Evaluation of the Performance of Lubricious Topcoats on IVD Aluminum Coated Fasteners", prepared for Army Material Command, Army Acquisition Pollution Prevention Support Office (AMC-AAPPSO), February, 1998.

Table 1: Suitable Materials for Army Applications

Alternative Category	Sub-Category Description	Major Category	Fasteners	Fasteners	Small Steel Hardware	Small Steel Hardware	Electrical Connectors	Electrical Connectors
		Description	less than 150 ksi ultimate tensile strength	greater than 150 ksi ultimate tensile strength	Simple	Complex		
		Substrate	steel	steel	steel	steel	steel	aluminum
ALTERNATE COATINGS								
Zinc	Plating		Yes	Possibly, but Hydrogen Embrittlement and/or Environmentally Assisted Cracking (HE EAC) possible	Yes	Yes	No	No
	Hot-Dip		Check Tolerances	Possibly, Check tolerances, EAC possible	Possibly	Possibly	No	No
	Inorganic		No	No	Possibly	No	No	No
Zinc Alloy	Sn Zn		Yes	Yes	Yes	Yes	Possibly	Possibly
	Zn Ni		Yes	Possibly, HE EAC possible	Yes	Yes	Possibly	Possibly
	Zn Co		Yes	Possibly, HE EAC possible	Yes	Yes	No	No
	Zn Fe		Yes	Possibly, HE EAC possible	Yes	Yes	No	No
Aluminum	IVD		Possibly, galling possible at high stress	Possibly, galling possible at high stress	Yes	No	Possibly	Possibly
	Electroplate		Possibly, galling possible at high stress	Possibly, galling possible at high stress	Yes	Yes	Possibly	Possibly
	Al-ceramic		Possibly, Check tolerances, use lubricant	Possibly, Check tolerances, use lubricant	Yes	No	Possibly	Possibly
Paints	organic		No	No	Possibly	Possibly	No	No
	metal-filled		No	No	Possibly	Possibly	No	No
	Duplex		Possibly	Possibly	Possibly	Possibly	No	No
Barrier-Only Metal Plating	Tin		No	No	No	No	No	Possibly
	Nickel		Possibly	Possibly	Possibly	Possibly	Possibly	Possibly
	Gold, Silver, and alloys		No	No	No	No	No	Possibly
ALTERNATE BASE MATERIALS								
Stainless Steels			Yes	No	Yes	Yes	Yes	Yes
Composite with electroless nickel			No	No	No	No	Possibly	Possibly

Table 2: Material Properties Required for Army Applications

Major Application Category	Sub-Category	Substrates Material	Corrosion Resistance (1)	Material Compatibility with Aluminum	Lubricity	Hydrogen Embrittlement (HE)	Environ-mentally Assisted Cracking (EAC)	Fatigue Resistance	Wear (2)	Adhesion (2)	Low Contact Resistance	Solderability	Low Cost	Availability	Environmental Friendliness
Fasteners	Less than 150 ksi	steel	Yes	Possibly	Yes	No	No	Possibly	Possibly	Yes	No	No	Yes	Yes	Yes
	Greater than 150 ksi - Grade 8 min.	Steel	Yes	Possibly	Yes	Yes	Yes	Yes	Possibly	Yes	No	No	Yes	Yes	Yes
Small steel hardware		steel	Yes	Possibly	No	Possibly	Possibly	Possibly	Possibly	Yes	No	No	Yes	Yes	Yes
Electrical Connectors		steel	Yes	Possibly	Possibly	No	No	No	Possibly	Yes	No	Possibly	Possibly	Yes	Yes
		aluminum	Yes	Possibly	Possibly	No	No	No	Possibly	Yes	Yes	Possibly	Possibly	Yes	Yes

(1) Cadmium is used as a corrosion resistant coating. The amount of corrosion resistance required will depend on the environment the material will be exposed.
(2) This property is not typically a primary concern for cadmium applications, but it may become an issue when significantly different types of materials are substituted for cadmium (i.e. organics).

Table 3: Material Performance in Material Property Categories

ID #	Alternative Category	Sub-Category Description	Specification	Class or Grade	Type	Minimum Thickness (mils)	Finish	Substrates Used On (s=steel, a=aluminum, ss=stainless, t=titanium)	Corrosion Resistance (1)	Material Compatibility to Aluminum	Lubricity (dry)
1	Cadmium	Electroplating	QQ-P-416	1	I	0.5	as-plated	s, a	7	8	9
2				1	II	0.5	chromated	s, a	9	8	9
3				1	III	0.5	phosphated	s, a	8	8	9
4				2	I	0.3	as-plated	s, a	6	8	9
5				2	II	0.3	chromated	s, a	8	8	9
6				2	III	0.3	phosphated	s, a	7	8	9
7				3	I	0.2	as-plated	s, a	5	8	9
8				3	II	0.2	chromated	s, a	7	8	9
9				3	III	0.2	phosphated	s, a	6	8	9
10	Zinc	Electroplating	ASTM B633	Fe/Zn 25	I	1	as-plated	s, a	6	6	2
11					II	1	colored chromate	s, a	8	6	2
12					III	1	colorless chromate	s, a	7	6	2
13					IV	1	phosphate	s, a	7	6	2
14				Fe/Zn 12	I	0.5	as-plated	s, a	5	6	8
15					II	0.5	colored chromate	s, a	7	6	8
16					III	0.5	colorless chromate	s, a	6	6	8
17					IV	0.5	phosphate	s, a	6	6	8
18				Fe/Zn 8	I	0.3	as-plated	s, a	4	6	8
19					II	0.3	colored chromate	s, a	6	6	8
20					III	0.3	colorless chromate	s, a	5	6	8
21					IV	0.3	phosphate	s, a	5	6	8
22				Fe/Zn 5	I	0.2	as-plated	s, a	4	6	8
23					II	0.2	colored chromate	s, a	4	6	8
24					III	0.2	colorless chromate	s, a	4	6	8
25					IV	0.2	phosphate	s, a	4	6	8
26		Hot-Dip	ASTM A153			1.7		s	9	6	2
27		Inorganic				2		s	9	6	2
28	Zinc Alloy	Sn/Zn	BAC 5899	1	I	0.5	as-plated	s, a, ss, t	7	8	7
29					II	0.5	chromate treated	s, a, ss, t	8	8	7
30				2	I	0.3	as-plated	s, a, ss, t	6	8	7
31					II	0.3	chromate treated	s, a, ss, t	7	8	7
32				3	I	0.2	as-plated	s, a, ss, t	5	8	7
33					II	0.2	chromate treated	s, a, ss, t	6	8	7
34		Zn/Ni	ASTM B841	1	A	0.2	colorless chromate	s, a	5	7	8
35					B	0.2	yellow chromate	s, a	6	7	8